

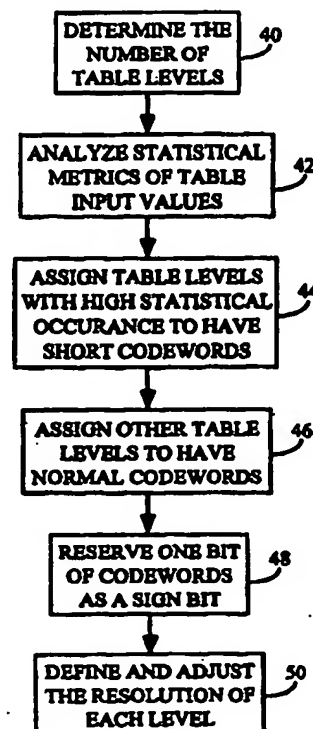
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(21) International Application Number: PCT/US97/21572 (22) International Filing Date: 25 November 1997 (25.11.97) (30) Priority Data: 60/032,541 10 December 1996 (10.12.96) US 08/911,526 12 August 1997 (12.08.97) US (71) Applicant: THOMSON CONSUMER ELECTRONICS, INC. [US/US]; 10330 North Meridian Street, Indianapolis, IN 46290-1024 (US). (72) Inventors: YU, Haoping; Apartment 3012, 3029 West 39th Street, Indianapolis, IN 46228 (US). CANFIELD, Barth, Alan; 10421 Indian Lake Boulevard North Drive, Indianapolis, IN 46236 (US). BEYERS, Billy, Wesley, Jr.; 6920 Woodcrest Drive, Greenfield, IN 46140 (US). LAM, Wai-man; 1325 Sunnyridge Road, Mohegan Lake, NY 10547 (US). (74) Agents: TRIPOLI, Joseph, S. et al.; GE & RCA Licensing Management Operation Inc., P.O. Box 5312, Princeton, NJ 08543 (US).			(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>

(54) Title: DATA EFFICIENT QUANTIZATION TABLE FOR A DIGITAL VIDEO SIGNAL PROCESSOR**(57) Abstract**

An MPEG coded and compressed video signal is received and decompressed for display. Prior to storing frames required for motion compensation in memory (14), pixel blocks are recompressed by quantizing (20) DPCM prediction error values (18) to reduce bandwidth and frame memory requirements. Fixed length quantization and dequantization tables (Fig. 2) have N levels (e.g., 15 levels), and each level has an associated output symbol of predominantly M bits (e.g., 4 bits), except that at least one of said N levels (e.g., level 7) is defined by a unique short symbol having less than M bits (e.g., 3 bits). One of the M bits may be reserved as a sign bit. Each time a short symbol is used to represent a data value, bandwidth and memory are reduced and/or preserved for other uses, for example, inserting overhead data into a fixed-size data stream. For large sequences of data, such as exists for video data for example, the reduction in memory and bandwidth is significant.



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DATA EFFICIENT QUANTIZATION TABLE FOR A DIGITAL VIDEO SIGNAL PROCESSOR

5 This invention concerns compression/decompression networks. Specifically, the invention concerns modifying the characteristics of compression/decompression tables to facilitate data throughput and memory efficiency.

10 Codeword resolution is important to accurately reconstruct coded data. Fixed-length quantization lookup tables allow a compression network to efficiently quantize and dequantize data using minimal processing. Quantization tables using a greater number of bits to represent output codewords allow better resolution than tables using a
15 fewer number of bits to represent output codewords. However, more bits require more memory for storing the data after quantization and a greater bandwidth to transfer the same data. Quantization tables are lossy in that, for a given quantization level, they compress several input data points of approximately the same value to one output value. During
20 reconstruction, the same dequantized value represents all data points within the resolution of a particular quantization level of the table. Data discrepancy depends upon the resolution of the table employed to compress and decompress the data. Known fixed-length quantization tables exhibit a number of levels dictated by the number of bits used to represent the output codewords, and all codewords are represented by
25 the same number of bits within a given table. For example, a table with three-bit output codewords has eight levels (2^3), and a four-bit table has sixteen levels (2^4). The average resolution of the table, and generally of each level, is the domain of the table divided by the number of levels in the table.

30 In quantization tables, output quantized data are represented by multiple-bit words, or symbols. It is herein recognized that for certain types of data, quantization tables employing symbols with less than the predominant number of bits per symbol for at least one quantization level can significantly reduce bandwidth and memory requirements. In
35 accordance with the principles of the present invention, compression and decompression tables have N levels associated with respective symbols of predominantly M bits, except that at least one level receiving values at a known general rate is compressed with a symbol having less than M bits.

A Brief Description of the Drawings

Figure 1 shows a four-bit quantization table according to the prior art.

Figure 2 shows a four-bit quantization table according to the principles of the present invention.

Figure 3 shows a block diagram of a compression/decompression network which may employ the present invention.

Figure 4 shows a flow chart defining one possible method of designing a table according to the principles of the present invention.

In an exemplary embodiment, each one of 15 quantization table levels is associated with a four-bit output codeword symbol, except for level seven which is associated with frequently occurring input data. In this case, a three-bit symbol is used. Each time a short symbol is used, bandwidth and memory are preserved for other uses. For large sequences of data, such as exists for video data for example, the reduction in memory and bandwidth is significant. The invention also pertains to dequantization tables.

The quantization table defined above is a hybrid, bi-length table. Depending upon the number of bits used to represent codewords, multiple table levels may be selected to produce the desired bandwidth reduction. Instead of a bi-length table, the hybrid table would be an N-length table, N being the number of levels having short codewords. Also, the number of bits in short symbols may vary from two to more than two if necessary. This requires a more complicated state machine to track the bit savings.

In general, fixed length tables exist to produce a fixed and known bit rate/bandwidth savings, with each data value being compressed to the same number of bits. Variable length tables exist to produce the minimum bit rate and the maximum bandwidth savings possible. For quantization tables, both fixed-length and variable length tables cause a certain amount of data loss and error. In situations which require a fixed or known reduction in bandwidth, a hybrid table allows a compression

system to maintain higher resolution within the reduced bandwidth. An example of such a situation is insertion of overhead information into a data stream of defined or known data size/rate/bandwidth.

Figure 1 shows a fixed length lossy quantization table known in the art. This table has a domain of 128 (-64 to 63 inclusive) and reduces input values, for example seven-bit values, to four-bit output symbols. Each symbol represents the quantized data value. Quantization table parameters include quantization level indexes with associated decision points, reconstruction levels, and quantized output codeword symbols.

The decision point sets the quantization boundary and identifies the input values for the associated output symbol (0000 ... 1110). Input values equal to the decision point value but greater than the preceding decision point value fall into that level, are represented by the associated symbol during compression, and will be represented by the reconstruction level upon decompression. For example, level index 0 has a decision point of -50, which includes input values from -50 to -64, is represented by symbol 0000, and will be reconstructed to a value of -57. Because the symbols are four bits long in this example, there are sixteen (2^4) possible levels for the table. However, when the tables (both Figure 1 and Figure 2) represent differential pulse code modulation (DPCM) prediction error values, the tables normally have an odd number of levels (15) to maintain the symmetry inherent in the prediction error values. DPCM processing will be explained later.

Each quantization level has an average resolution of 8.5 (e.g., a domain of 128 divided by 15 levels), but any one level may actually represent more or less than the average resolution depending upon other factors unique to an individual compression/decompression network. For any given input value within the domain of the table, the input value is classified with respect to a decision point wherein the input value is less than or equal to the decision point but greater than the preceding decision point. The index of the decision point then identifies the four-bit symbol used to represent the data value. Upon dequantization, the four-bit symbol identifies an index which leads to a reconstruction value. The reconstruction value is equal to or approximately equal to the original input data value.

Figure 2 shows a table implementing the principles of the present invention. The table has a domain of 128 (-64 to 63 inclusive) and reduces seven-bit input values to one of fourteen four-bit output symbols

or one three-bit output symbol (level 7). The table has fifteen possible quantization levels, compared to a maximum of sixteen possible levels in a typical four-bit table. Unrelated to DPCM processing contained in both tables of Figures 1 and 2, the number of possible levels is reduced (from 5 2^n maximum) because one of the symbols (000) contains only three bits. Decreasing the number of levels within the table by one reduces maximum resolution for the table by an average of approximately 6.3 % for each level. For the domain of 128, a sixteen level table has an average resolution of 8.0 for each level, and a fifteen level table has an 10 approximate average resolution of 8.5 for each level (e.g., a domain of 128 divided by 15 levels). A three-bit table would only have eight possible levels. Using a fifteen level table instead of an eight level, three-bit table adds seven levels, and represents an average 87.5 % increase in resolution for each level. If the three-bit symbol (000 in this case, for 15 example) is placed within the fifteen level table such that it is accessed frequently, then the reduction in bandwidth and memory requirements become significant and outweigh the loss in data resolution. Thus, in accordance with the present invention, in a quantization table having N levels (e.g., 15 levels), each level having an associated output symbol of 20 predominantly M bits (e.g., 4 bits), at least one level (e.g., level 7) is associated with a frequently occurring value and a corresponding symbol having less than M bits (e.g., 3 bits).

A decompression network must identify the three-bit and four-bit symbols when the data is retrieved for decompression. This is facilitated 25 by reserving the bit pattern of the three-bit symbol. For example, in Figure 2 only the three-bit symbol has the pattern "000." The first three bits of all symbols are reserved such that whenever the bit pattern of "000" occurs in these bits, the network identifies the three-bit symbol and does not process a fourth bit when dequantizing and reconstructing 30 the eight-bit data value. For all four-bit patterns of symbols any chosen three-bit pattern will occur twice. Only one of the occurrences of the three-bit symbol will represent a quantization level in a table, because the network can only recognize one level for the three-bit symbol without other information. Any three-bit pattern may be used in the case of a 35 four-bit table, and only the three-bit symbol may have the reserved pattern.

For a given system in which the tables are used, if a designer determines that it is more efficient to use two three-bit symbols instead

of one in a predominantly four-bit table, then the quantization and dequantization tables may be designed with fourteen or fewer levels. Any two-bit pattern, such as "00," in any of the bit positions will occur only four times within the sixteen possible symbols. The twelve levels
5 that do not have the short symbol bit pattern are assigned four-bit output symbols. Using a two-bit pattern to identify the three-bit symbol leaves one bit to distinguish between three-bit symbols which will uniquely identify two different levels. This is the same as having two unique three-bit patterns, each of which will occur twice within the sixteen
10 possible symbols. Therefore, fourteen of the sixteen levels are available for this arrangement.

The three-bit symbol is positioned so as to optimize the chances of this symbol being associated with frequently occurring input data values during quantization. Therefore, a particular system must be evaluated in
15 advance so as to statistically identify where to place the three-bit symbols. The system may include more than the compression/decompression network if necessary to accurately make statistical measurements. For example, the table in Figure 2 processes Differential Pulse Code Modulation (DPCM) prediction error values
20 typically derived from a prediction network. Such prediction networks are well known. Within compression networks utilizing DPCM, a prediction network uses previous data values to predict the next data value. The difference between the actual value and the predicted value is determined and this difference is the prediction error. The absolute
25 value of the prediction error is generally numerically less than either the actual or predicted values, and therefore may be accurately represented with fewer bits.

DPCM prediction error values generally occur symmetrically about zero error and statistically occur more frequently at and close to zero
30 error approximating a bell curve. The frequency of where the error values occur may be measured before the table is designed by deriving the distribution of all prediction error values which will be input into the system. With this information, a three-bit symbol is placed where the likelihood of use is the greatest, thereby minimizing bandwidth and
35 memory requirements while maintaining processing efficiency. The resolution of the level(s) to be represented by the three-bit symbols may be adjusted to optimize the use of the three-bit symbols. In Figure 2, the three-bit symbol is placed about zero where the prediction error is most

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likely to occur for this system. This particular level (level 7) has a resolution of six, from 3 to -2, because the table level placement is optimized for statistical occurrence. Again, depending upon the type of compression network involved, the placement of the three-bit symbol depends upon the statistical occurrence of data values the quantization and dequantization tables receive. The statistically optimal placement may vary between different types of systems without affecting the implementation of short codeword symbols.

The symbols may be designed to take advantage of the symmetry of the input data, such as DPCM input data represented by prediction error values, for example. The table in Figure 2 is based on DPCM processing where the input values will occur symmetrically about zero. Therefore, one bit of the symbol may be reserved as a sign bit. The extreme right bit (the least significant bit) of symbols in levels 0 to 6 is "0", whereas this bit for symbols in levels 8 to 14 is "1". The network then must only decode three bits of the four-bit symbol upon reconstruction, and less complicated circuitry may add the correct sign to the reconstructed data value.

Figure 3 illustrates one possible system in which quantization and dequantization tables employing the present invention may be used. Compression network 12 receives input data at its input 10 from an input network (not shown). The input data is sent to quantizer 20 and combiner 22. Quantizer 20 passes necessary input values to predictor 18 which generates a prediction value for the value being quantized. Combiner 22 receives the prediction value and subtracts it from the original input value associated with the prediction value. The difference, which is the prediction error value, is received by quantizer 20, which quantizes the prediction error value using a quantization table designed in accordance with the principles of the present invention. Compressed data output symbols from quantizer 20 are sent to frame memory 14.

When data is needed by an output network (not shown), decompression network 16 receives the compressed data from frame memory 14, and dequantizer 26 dequantizes the compressed prediction error values using a dequantization table designed in accordance with the principles of the present invention. The prediction error values pass to predictor 24, which is similar to predictor 12, and a prediction value is generated. The prediction value is sent back to dequantizer 26, and added to the decompressed prediction error value resulting in the

corresponding reconstructed original input value or a close approximation thereof. The reconstructed values are sent to the output network.

The input network may be a signal processor in an MPEG compatible television receiver, which receives audio and video signals encoded and compressed in an MPEG format. The receiver decodes and decompresses the received signal and provides 8 x 8 blocks of eight-bit image picture elements (pixels) to input 10. The corresponding output network may be a display processor compatible with a standard or high definition display. The display processor requires random access to pixel blocks within a given image frame to derive motion compensation information. Frame memory 14 stores the image frames until the display processor needs them.

Figure 4 illustrates one method of designing a quantization and dequantization table for use in the network of Figure 3 as described above. It is not necessary to follow the exact order of each step to successfully design a table. For example, step 46 may occur before step 44, and step 48 may occur at any time. In step 40, the number of levels the table will have is determined. This depends upon the number of bits each symbol will have, the type of data to be received by the table, the type of processing the network will do to the data, and other variables particular to the system employed. In step 42, the data and system are statistically analyzed to determine and classify the frequency at which input data values will occur. The table level(s) which will receive frequently occurring data is/are assigned the short symbol(s) in step 44. The other levels are assigned normal length symbols in step 46. In step 48, one bit of the symbols is reserved as a sign bit, which may be processed separately by less complicated circuitry to save and add the correct sign of the data. Finally, in step 50, the resolution of each level is defined. The levels may be adjusted so that some levels have a finer resolution than other levels. This determination is also based upon the statistical analysis of the data and system employed.

The described quantization network should not be confused with Huffman coding, which is well known to persons skilled in the art. Huffman coding is a lossless statistical entropy coding, and has codeword lengths which are both less than and greater than the average output codeword length. Also, each input into an encoder employing Huffman coding has a unique symbol generated at the output of the encoder. It is impossible to use Huffman coding in a compression system with a fixed

bit rate because Huffman coding is entropy coding. Huffman coding does not provide the necessary control to provide a fixed bit rate.

The method described herein according to the present invention facilitates memory and bandwidth reduction even if the frequency of occurrence for each level is approximately equal because the method and apparatus are applied in a lossy system. Symbols according to the principles of the present invention represent a range of input data determined by decision points associated with quantization levels. The original data typically is not exactly reproduced upon decompression.

Also, implementing Huffman coding instead of the method described above would result in more complicated hardware and symbol lengths longer than the average/dominant symbol size, because each codeword must have a unique pattern to differentiate between codewords. That is, if a four bit codeword was "0101," codewords with more bits could not have "0101" in the first four bits or the decoder would incorrectly identify the bit pattern. In quantization tables incorporating the invention, only the short symbol has a unique bit pattern for N bits. Longer bit patterns may be repeated after the first N bits. This requires a significantly less complicated network compared to Huffman coding.

CLAIMS:

1. A method for defining a compression/decompression table
5 within a compression/decompression network, the steps comprising:
 (a) providing a compression/decompression table with a
predetermined number of levels N, each of said levels being associated
with respective symbols of predominantly M bits;
 (b) analyzing the statistical occurrence of input values to said
10 table; and
 (c) defining a symbol to have a unique pattern of less than M bits
to produce a short symbol, said short symbol representing one of said
levels receiving input data at a desired rate.
- 15 2. The method of claim 1, wherein;
the number of short symbols is significantly less than the number
of other M-bit symbols.
3. The method of claim 1, further comprising:
20 (d) reserving a sign bit in the bit pattern of said M-bit symbols;
and
 (e) defining the resolution of each level within said table such
that some quantization levels have greater resolution than other
quantization levels.
- 25 4. The method of claim 1, whereint:
said short symbol is represented by a predetermined bit pattern in
the initial bit sequence of said symbol.
- 30 5. The method of claim 1, wherein:
said short symbol is one bit less than said M-bit symbols.

6. Apparatus for compressing/decompressing data, comprising:
an input network (12) for receiving data and formatting said data;
a compression network (20) including a compression table for
5 compressing said data into compressed data; and
memory (14) for storing said compressed data; wherein
said compression table includes M-bit symbols representing N
quantization levels, except that at least one of said N levels is defined by
a unique short symbol having less than M bits, said one of said N levels
10 receiving input data at a desired rate.

7. The apparatus of claim 6, further comprising:
a decompression network (26) including a decompression table for
receiving said compressed data and producing reconstructed data; and
15 an output network for receiving said reconstructed data; wherein
said decompression table includes symbols of M bits and at least
one short symbol of less than M bits.

8. The apparatus of claim 6, wherein:
20 a predetermined bit pattern of bits of each of said symbols is
associated with a quantization level index and reconstruction level value.

9. The apparatus of claim 6, wherein:
said short symbol is represented by a unique, predetermined bit
25 pattern in the initial bit sequence of said symbol.

10. A method for processing MPEG coded image representative
data, the steps comprising:
(a) decompressing said data to produce decompressed data;
30 (b) recompressing said decompressed data to produce
recompressed data; and
(c) storing said recompressed data; wherein
said recompressing step is facilitated by a compression table having
N levels, each of said N levels having an associated output symbol of
35 predominantly M bits, except that at least one of said N levels is defined
by a unique short symbol having less than M bits, said one of said N
levels receiving input data at a desired rate.

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11. The method of claim 10, wherein;
the number of short symbols is significantly less than the number
of other M-bit symbols.

5 12. The method of claim 10, wherein:
said input data values represent differential values.

13. The method of claim 10, wherein:
said input data values represent DPCM prediction error values.

10

14. The method of claim 10, wherein:
said input data represents pixel blocks.

15 15. The method of claim 10, wherein:
said recompression step is a quantizing step and said compression
table is a fixed-length quantization table.

20 16. The method of claim 10, wherein:
said short symbol is represented by a predetermined bit pattern in
the initial bit sequence of said symbol.

17. The method of claim 10, wherein:
said short symbol has one less bit than said M-bit symbols.

25 18. The method of claim 10, further steps comprising:
(d) decompressing said recompressed data to produce
reconstructed data; and
(e) outputting said reconstructed data to an output network;
wherein

30 said reconstructed data is generated in a substantially inverse
manner to said recompression step.

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Level Index	Decision Point	Reconstruction Level	Quantization Output Codeword Symbol
0	-50	-57	0000
1	-39	-45	0001
2	-29	-34	0010
3	-20	-25	0011
4	-13	-17	0100
5	-7	-10	0101
6	-2	-5	0110
7	3	0	0111
8	8	5	1000
9	14	10	1001
10	21	17	1010
11	30	25	1011
12	40	34	1100
13	51	45	1101
14	63	57	1110

FIGURE 1
PRIOR ART

Level Index	Decision Point	Reconstruction Level	Quantization Output Codeword Symbol
0	-50	-57	1110
1	-39	-45	1100
2	-29	-34	1010
3	-20	-25	1000
4	-13	-17	0110
5	-7	-10	0100
6	-2	-5	0010
7	3	0	000
8	8	5	0011
9	14	10	0101
10	21	17	0111
11	30	25	1001
12	40	34	1011
13	51	45	1101
14	63	57	1111

FIGURE 2

2 / 2

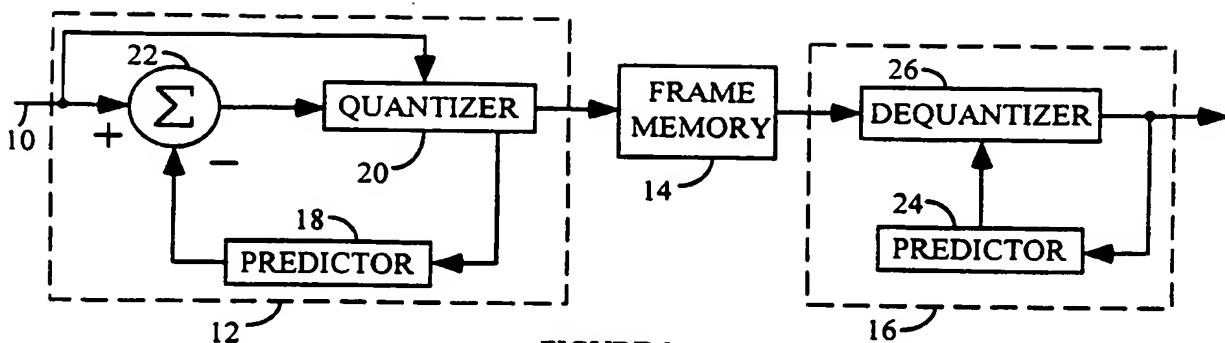


FIGURE 3

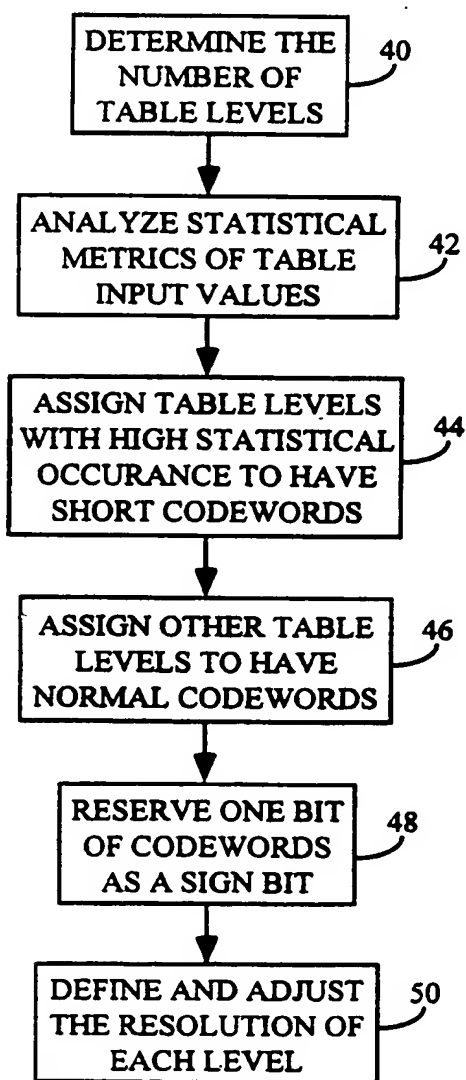


FIGURE 4

INTERNATIONAL SEARCH REPORT

National Application No
PCT/US 97/21572

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04N7/30 H04N7/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 535 571 A (EASTMAN KODAK CO) 7 April 1993 see column 2, line 10 - column 2, line 16 see column 4, line 26 - column 7, line 48 see figure 4 see claims 1,2,7	1,2,4, 6-9
Y		3,10-16, 18
A		5,17
Y	EP 0 627 858 A (MATSUSHITA ELECTRIC IND CO LTD) 7 December 1994 see column 3, line 46 - column 4, line 16	10-16,18
A		17
Y	EP 0 660 612 A (SHARP KK) 28 June 1995 see column 6, line 43 - column 7, line 28	15
A		10
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

I. International Application No

PCT/US 97/21572

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	see column 2, line 57 - column 5, line 57 see figures 1,2,8 ----	1,10
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